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ISOMERIC STATE AND ROTATIONAL BAND IN ^{158}Ho

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Résumé. — Le noyau impair-impair ^{158}Ho a été étudié au moyen des réactions ^{159}Tb(α, 5n)^{158}Ho et ^{160}Dy(p, 3n)^{158}Ho. Un état isomérique de période $T_{1/2}$ = (29 ± 3) ns a été mis en évidence. Une bande de rotation a été développée jusqu'au spin 16^-.

Abstract. — The odd-odd ^{158}Ho nucleus is studied by means of the reactions ^{159}Tb(α, 5n)^{158}Ho and ^{160}Dy(p, 3n)^{158}Ho. The life-time of an isomeric state is measured as $T_{1/2}$ = (29 ± 3) ns. A rotational band is developed up to spin 16^-.

1. **Introduction.** — In the framework of a systematic study of the spectroscopy of neutron-deficient holmium isotopes, the level scheme of the odd-odd nucleus ^{158}Ho has been investigated.

A previous investigation by Stenström and Jung [1] determined the genetic relationships and half-lives of ^{158}Ho isomers. Recently Abdurazakov *et al.* [2] and Harmatz and Handley [3] have investigated the decay scheme of the nucleus ^{158}Er → ^{158}Ho. As a result of their investigations the ground state of ^{158}Ho is found to have spin and parity 5^+ corresponding to 67 protons and 91 neutrons with a p $7/2^-$ [523] ↑ n $3/2^-$ [521] ↑ configuration. An isomeric state ($T_{1/2}$ = 27 min.) in ^{158}Ho with energy 67.3 keV is known which has been interpreted as having spin and parity 2^- and which corresponds to possible configurations :

p $1/2^+$ [411] ↓ n $5/2^-$ [523] ↓ Ref. [2]
p $7/2^+$ [404] ↓ n $3/2^-$ [521] ↑ Ref. [3]
p $7/2^-$ [523] ↑ n $3/2^+$ [402] ↓

It is the purpose of this letter to discuss the above possibilities and compare them with our data which concern the levels of ^{158}Ho studied by in beam spectroscopic methods in the reactions (α, xnγ) and (p, xnγ).

2. **Experimental procedure and results.** — The in beam experiments were carried out at the Grenoble cyclotron. For the ^{159}Tb(α, 5n) reaction, a monoisotopic terbium foil target of 5 mg/cm^2 was used. The ^{160}Dy(p, 3n) reaction was performed with a 5.5 mg/cm^2 85 % enriched $^{160}Dy_2O_3$ target. The study of excitation functions suggested that alpha and proton particle energies of approximately 63 MeV and 43 MeV respectively were the most favourable for the production of ^{158}Ho. Gamma lines belonging to

TABLE I

Summary of the experimental results

E_γ	I_γ	Assignment	
67.3 ± 0.1	95 ± 8	^{158}Ho	$2^- \to 5^+$
70.9 ± 0.1	72 ± 6	^{158}Ho	$6^- \to 5^-$
98.9 ± 0.1	540 ± 50	^{158}Dy	
100.6 ± 0.2	185 ± 19	^{158}Ho	$7^- \to 6^-$
115.1 ± 0.2	200 ± 20	^{158}Ho	$8^- \to 7^-$
156.9 ± 0.1	1 000 ± 90	^{158m}Ho	$5^- \to 5^+$
159.3 ± 0.2	210 ± 21	^{158}Ho	$9^- \to 8^-$
166.1 ± 0.1	250 ± 26	^{158}Ho, ^{159}Ho	$10^- \to 9^-$
171.5 ± 0.3	w	^{158}Ho	$7^- \to 5^-$
213.8 ± 0.2	155 ± 16	^{158}Ho, ^{158}Dy	$11^- \to 10^-$
215.7 ± 0.2	163 ± 17	^{158}Ho	$8^- \to 6^-$
218.2 ± 0.1	1 320 ± 80	^{158}Dy	
221.9 ± 0.2	89 ± 12	^{158}Ho	$12^- \to 11^-$
255.9 ± 0.3	55 ± 7	^{158}Ho	$13^- \to 12^-$
274.4 ± 0.3	77 ± 8	^{158}Ho	$9^- \to 7^-$
277.4 ± 0.4	35 ± 12	^{158}Ho	$14^- \to 13^-$
286.4 ± 0.4	35 ± 12	^{158}Ho	$15^- \to 14^-$
320.4 ± 0.1	850 ± 80	^{158}Dy	
325.4 ± 0.2	210 ± 21	^{158}Ho	$10^- \to 8^-$
379.9 ± 0.2	163 ± 18	^{158}Ho	$11^- \to 9^-$
425.4 ± 0.2	50 ± 5	^{158}Dy	
435.8 ± 0.2	246 ± 25	^{158}Ho	$12^- \to 10^-$
477.8 ± 0.2	107 ± 13	^{158}Ho	$13^- \to 11^-$
533.3 ± 0.2	155 ± 16	^{158}Ho	$14^- \to 12^-$
563.8 ± 0.3	134 ± 20	^{158}Ho	$15^- \to 13^-$
617.0 ± 0.3	100 ± 12	^{158}Ho	$16^- \to 14^-$

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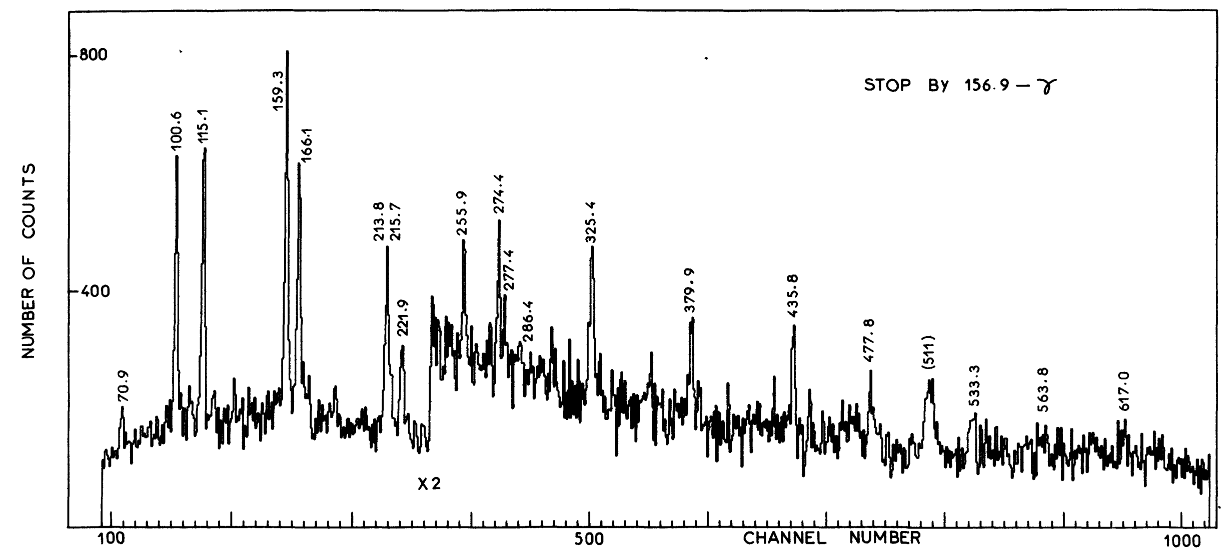

FIG. 1. — Example of coincident spectrum (stop by 156.9 keV-γ).

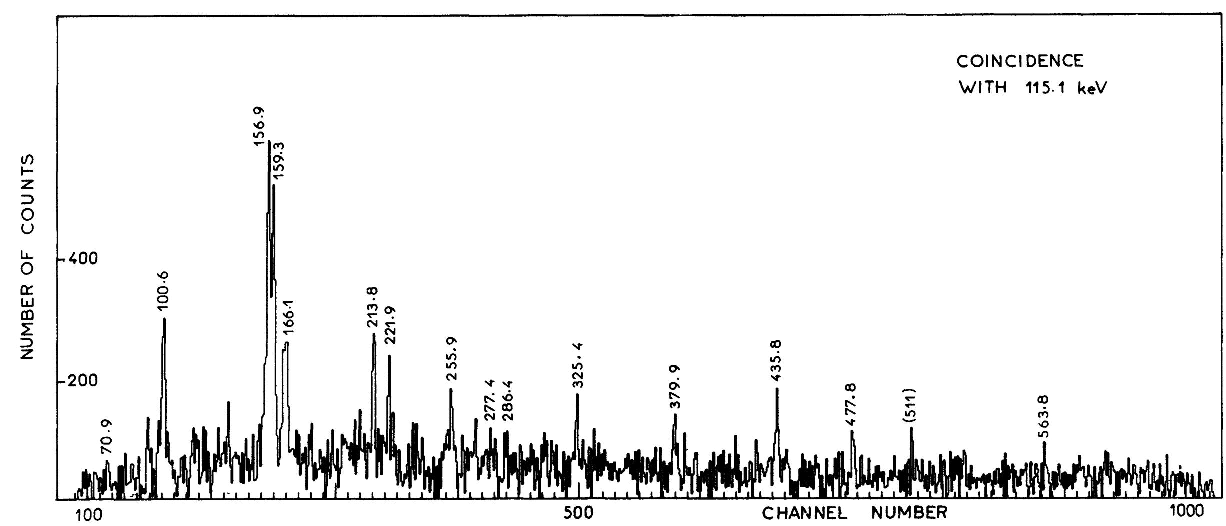

FIG. 2. — Example of coincident spectrum (115.1 keV-γ).

^{157}Ho and ^{159}Ho and their daughter products were observed in the spectrum due to the (α, 6n) and (α, 4n) reactions.

The experimental information consists of γ-ray spectra (in and out of beam), the life-time of the isomeric state measured using the cyclotron pulses and the prompt and delayed γ-γ coincidences. The results of our experiments are summarized in table I and in figures 1, 2, 3 and 4. In table I only the energies and the relative γ-ray intensities for the lines of ^{158}Ho and ^{158}Dy are tabulated. A spectrum obtained using the delayed coincidence method is presented in figure 1. In this figure the 156.9 keV γ-ray is taken as the gate STOP. Figure 2 gives an example of the prompt coincidences for the 115.1 keV γ-ray. The decay curve for the 156.9 keV line of ^{158}Ho is shown in figure 3.

3. **Data analysis and results.** — In the course of measurement of in and out of beam gamma spectra, an intense delayed gamma line at 156.9 keV was found to decay with a half-life of (29 $\pm$ 3) ns. A comparison of this value with those assigned for the isomeric states in odd-odd holmium isotopes is given in the following table.

	^{164}Ho [4]	^{162}Ho [5, 6]	^{160}Ho [5]	^{158}Ho
	—	—	—	—
Spin	6^-	6^-	(5^-)	
$T_{1/2}$	37.5 min.	68 min.	60 ns	29 ns
Energy	139 keV	106 keV	118.1 keV	156.9 keV

Thus, while both the ^{162}Ho and ^{164}Ho nuclei seem to have a 6^- isomeric state with the

$$\text{p } 7/2^- \ [523] \uparrow \text{n } 5/2^+ \ [642] \uparrow$$

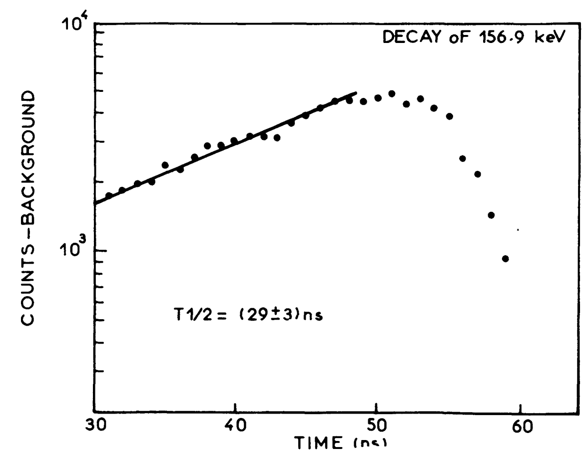

FIG. 3. — The decay of the 156.9 keV peak.

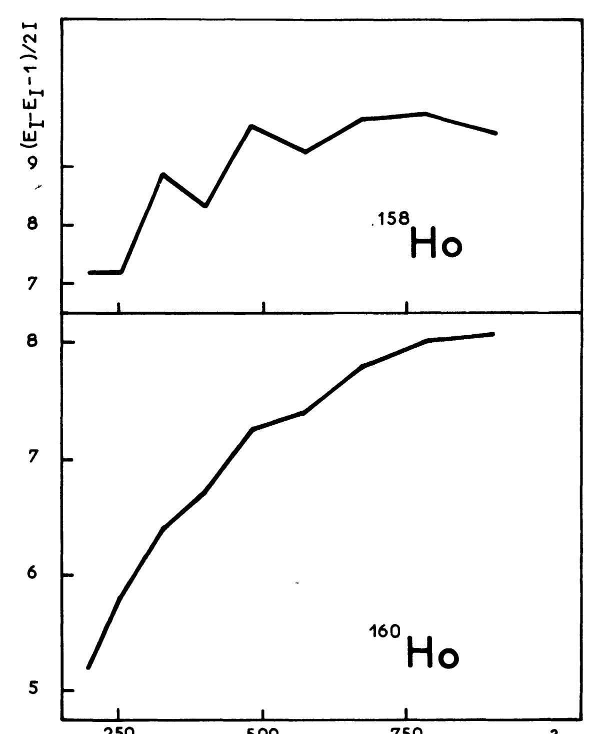

FIG. 4. — Plot of effective inverse moments-of-inertia associated with individual cascade transitions for ^{158}Ho and ^{160}Ho.

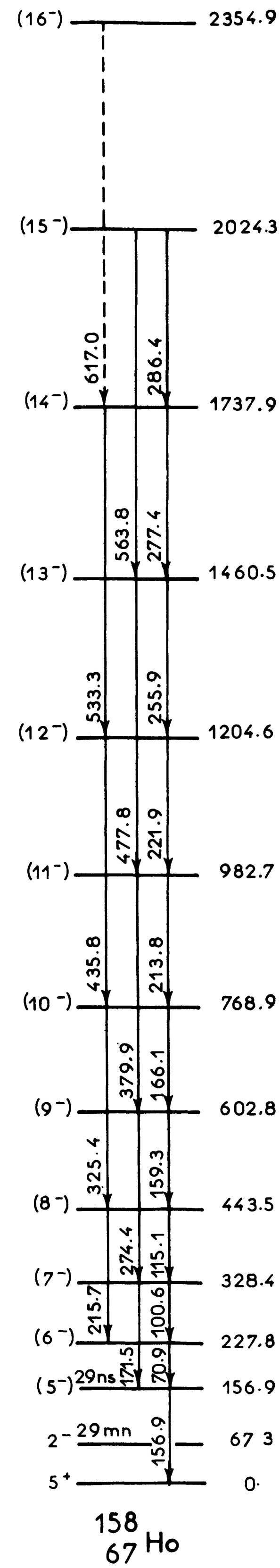

FIG. 5. — Proposed level scheme of ^{158}Ho.

configuration, the isomeric state observed at 118.1 keV in ^{160}Ho apparently has not this configuration as reported by Leigh, Stephens and Diamond [5]. These authors indicated that the 6^- state should also occur in ^{160}Ho and the rotational band observed is probably based on this state with the configuration 6^-, p $7/2^-$ [523] $\uparrow$ n $5/2^+$ [642] $\uparrow$. This conclusion was based on the very great similarity between the sequence of γ-rays transitions in both ^{162}Ho and ^{160}Ho. Moreover the oscillations in the energy level spacings for ^{162}Ho and ^{160}Ho obtained by plotting

$$(E_I - E_{I-1})/2\,I \text{ vs } f(2\,I)^2$$

are in phase. The isomeric state could be a 5^- state with the configuration p $7/2^-$ [523] $\uparrow$ n $3/2^+$ [402] $\downarrow$.

With regard to the nucleus ^{158}Ho, it must be noted that the sequence of γ-transition is different from that in ^{160}Ho. This discrepancy may be explained by the presence of the p $7/2^-$ [523] Nilsson level in the configuration which shows strong perturbation by Coriolis coupling. The increasing perturbation of the p 7/2$^-$ [523] band with decreasing mass number is indicated by the variation of the strength of fluctuations in neighbouring ^{157}Ho and ^{159}Ho nuclei [7]. Figure 4 shows this in a plot of $f(2\,I)^2$ for ^{160}Ho and ^{158}Ho. It is clear that the perturbation in the energy level spacing of ^{158}Ho is stronger than that in ^{160}Ho. If we suppose that the curves $(E_I - E_{I-1})/2\,I$ must be in phase in both ^{160}Ho and ^{158}Ho, the 156.9 keV state of spin 5$^-$ must be assigned as the isomeric state in the ^{158}Ho nucleus. The spin $I = K = 6^-$ might be attributed to the head of the rotational band.

However, two other assumptions are also possible :

1) The 6$^-$ state could be attributed as the isomeric state and considered as the head of the rotational band.

2) The isomeric state could be assigned as the 5$^-$ state by supposing a weak transition between the 6$^-$ and 5$^-$ state. We could not see a gamma line of such low energy with our experimental arrangement; if present, it is undoubtedly highly converted and will be difficult to observe. In this case the γ-ray of 72.9 keV could represent the transition between the 7$^-$ and 6$^-$ states.

By choosing the spin and parity of the isomeric state as 5$^-$, a possible configuration for this state is p 7/2$^-$ [523] $\uparrow$ n 3/2$^+$ [402] $\downarrow$. According to Gallagher-Moszkowski's rule, the 2$^-$ state of 67.3 keV in ^{158}Ho is the lower member of the doublet. However, this situation leads to a different interpretation from that given in refs. [2, 3].

4. **Conclusion.** — *a*) The level scheme of ^{158}Ho proposed on the basis of our experiments is shown in figure 5.

b) The rotational band observed in ^{158}Ho is highly perturbed by Coriolis coupling. This is due to the fact that the orbits of the proton and neutron states originate from high-*j* shells of $h_{11/2}$ and $i_{13/2}$ respectively and to the fact that with decreasing A the perturbation increases rapidly in the neighbouring odd-A nuclei.

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References

[1] STENSTRÖM, T. and JUNG, B., *Nucl. Phys.* **64** (1965) 209.

[2] ABDURAZAKOV, A. S., GROMOV, K. Ya., ZHELEV, Zh. T., KALINNIKOV, V. G., LIPTAK, Ya., NAZAROV, U. K. and URBANETS, Ya., *Sov. J. Nucl. Phys.* **8** (1969) 367.

[3] HARMATZ, B. and HANDLEY, T. H., *Nucl. Phys. A* **191** (1972) 497.

[4] JØRGENSEN, M. H., NIELSEN, O. B. and SKILBREID, O., *Nucl. Phys.* **84** (1966) 569.

[5] LEIGH, J. R., STEPHENS, F. S. and DIAMOND, R. M., *Phys. Lett.* **33B** (1970) 410.

[6] EKSTRÖM, C., NORELAND, T., OLSMATS, M. and WANNBERG, B., *Nucl. Phys. A* **135** (1969) 289.

[7] DIAMOND, R. M., *International Conference on the Properties of Nuclei far from the Region of β Stability*, Leysin (1970).